BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: ΔV Requirements to Change Planetary Mission Periapsis Altitude
Case 720

DATE: November 16, 1967

FROM: C. L. Greer

ABSTRACT

On manned planetary encounter missions the quality and quantity of data returned from both on-board and remote sensors are increased by reducing the spacecraft planetary passage distance. Adjusting periapsis altitude at planet encounter is equivalent to changing the departure asymptote of the spacecraft trajectory. It is shown that the ΔV requirement to change an off-nominal departure asymptote to nominal is approximated by $V_\infty \Delta\phi$, where $\Delta\phi$ is the angle between the respective departure asymptotes. An upper bound estimate of ΔV is $0.6\ V_\infty\ \Delta R_p/R_p$, where R_p is the pericenter distance.

Evaluation of three missions selected by the planetary Joint Action Group (JAG) as their baseline missions reveals that the ΔV requirements to achieve a 300 km periapsis altitude at each planet may be significant. Therefore, the choice of a nominal trajectory for mission analysis and planning is important. If ballistic trajectories with close planet passage do not exist, it will be necessary to make a tradeoff between ΔV requirements and system requirements associated with data acquisition.

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(NASA-CR-154652) REQUIREMENTS TO CHANGE PLANETARY MISSION DELTA PERIAPSIS ALTITUDE (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

INTRODUCTION

On manned planetary encounter missions a significant quantity of data generated during planet encounter will be from on-board sensors, such as a telescope camera system, wide field camera, multi-spectral camera, multi-spectral scanner, magnetometer and radar imager. Generally, the resolution of the photographic systems is inversely proportional to the distance from the planet and the resolution of the radar imager is inversely proportional to the fourth power of the distance from the planet. The amount of data collected from the sensors carried by aero drag probes, landers, etc., will be dependent on the bit-rates of the sensors. The bit-rate is inversely proportional to the square of the transmission distance. Thus, the quantity and quality of data returned from both on-board and remote sensors are increased by reducing the spacecraft periapsis passage distance.

Pending further investigation, a nominal periapsis altitude no closer than 300 km appears reasonable at both Venus and Mars. Recent studies of encounter mission trajectories have not constrained the periapsis altitude, so the existence of free ballistic trajectories having a periapsis altitude of 300 km has not been shown in every case. It is shown that the ΔV requirements to achieve 300 km periapsis altitude may be significant.

TECHNICAL DISCUSSION

In general, analyses of planetary missions use patched conic sections to calculate heliocentric trajectories. The planetocentric portion of the trajectory is determined by the approach and departure asymptotes of the heliocentric transfer legs. The corresponding periapsis altitude is computed in order that the spacecraft trajectory have the appropriate turn angle (Figure 1). Because of the technique used, periapsis altitudes vary from beneath the surface to several thousand kilometers above the surface.

The turn angle and periapsis altitude satisfy the equation:

$$\sin (\phi/2) = 1/(1 + R_p V_\infty^2/\mu) \qquad (1)$$

where

ϕ is the turn angle,
R_p is the pericenter distance,
V_∞ is the hyperbolic excess velocity, and
μ is the gravitational parameter.

A change in R_p yields a different ϕ value, which is equivalent to changing the departure (approach) asymptote if the approach (departure) asymptote is fixed. If the spacecraft goes through a turn angle other than nominal, a ΔV must be applied to change the departure asymptote to coincide with the nominal departure asymptote. The departure asymptotes may be thought of as vectors having magnitude V_∞, and the ΔV requirement (from Figure 1) is

$$\Delta V = 2V_\infty \sin \frac{\Delta\phi}{2} \qquad (2)$$

For $\Delta\phi < 20°$, $\sin \frac{\Delta\phi}{2} \simeq \frac{\Delta\phi}{2}$, which implies

$$\Delta V = V_\infty \Delta\phi. \qquad (3)$$

To compute the ΔV required to change periapsis altitude to 300 km, the difference in turn angles, $\Delta\phi$, must be determined. The nominal turn angle may be found by using Figure 2, which contains the graphs of turn angle, ϕ, versus $R_p V_\infty^2$ for Venus and Mars. The turn angle for a periapsis altitude of 300 km may be obtained from Figure 3.

An upper bound estimate on the value of $\Delta\phi$ for small changes in R_p may be obtained in the following fashion. Differentiating Equation (1) yields:

$$-d\phi = \frac{2}{e}\sqrt{\frac{e-1}{e+1}}\,\frac{dR_p}{R_p} \qquad (4)$$

where $e = 1 + R_p V_\infty^2$. The coefficient of dR_p/R_p has a maximum value approximately 0.6 (Figure 4). Thus, for small values of ΔR_p the bound estimate is $\Delta\phi \simeq d\phi \leq 0.6\ \Delta R_p/R_p$. The resulting bound on ΔV is $0.6\ V_\infty\ \Delta R_p/R_p$.

In changing the periapsis altitude, the position of periapsis relative to the approach asymptote is altered by $\Delta\phi/2$ degrees. Thus, the same technique may be used to determine the ΔV requirement to alter periapsis position.

APPLICATION

The technique described was used to estimate the ΔV requirements to achieve a 300-km periapsis altitude at planet encounter for three planetary encounter missions selected by the planetary Joint Action Group (JAG) as their baseline missions. The following table lists the type of trajectory, the parameters used to compute $\Delta\phi$, the corresponding bound estimate on $\Delta\phi$, and the ΔV to achieve a 300-km periapsis altitude.

Mission	V_∞ (km/sec)	Nominal R_p (km)	$\Delta\phi$ (degrees)	Bound Estimate of $\Delta\phi$ (degrees)	ΔV (km/sec)
1975 Mars	8.56	3350*	1.5	3.7	.224
1977 Triple Planet					
1st Venus Encounter	6.70	6787	1.0	2.2	.117
Mars Encounter	4.37	7290	17.0	16.9	1.30
2nd Venus Encounter	7.13	6804	2.0	2.3	.250
1978 Dual Planet					
Venus Encounter	10.46	7270	3.3	4.3	.602
Mars Encounter	5.41	3530	1.0	1.8	.094

*Nominal R_p is less than planet radius.

SUMMARY AND CONCLUSION

On manned planetary encounter missions the quality and quantity of data returned from both on-board and remote sensors are increased by reducing the spacecraft planetary passage distance. If periapsis altitude is to be altered, either the approach or departure asymptote may be changed. The ΔV requirement in either case is approximated by $V_\infty \Delta\phi$ where $\Delta\phi$ is the difference in turn angles.

From the data above, it can be seen that the ΔV requirement for close planet passage may be significant. Therefore, the choice of a nominal trajectory for mission analysis and planning is important. If ballistic trajectories with close planet passage do not exist, it will be necessary to make a tradeoff between ΔV requirements and system requirements associated with data acquisition.

C. L. Greer

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Attachments
  Figures 1-4

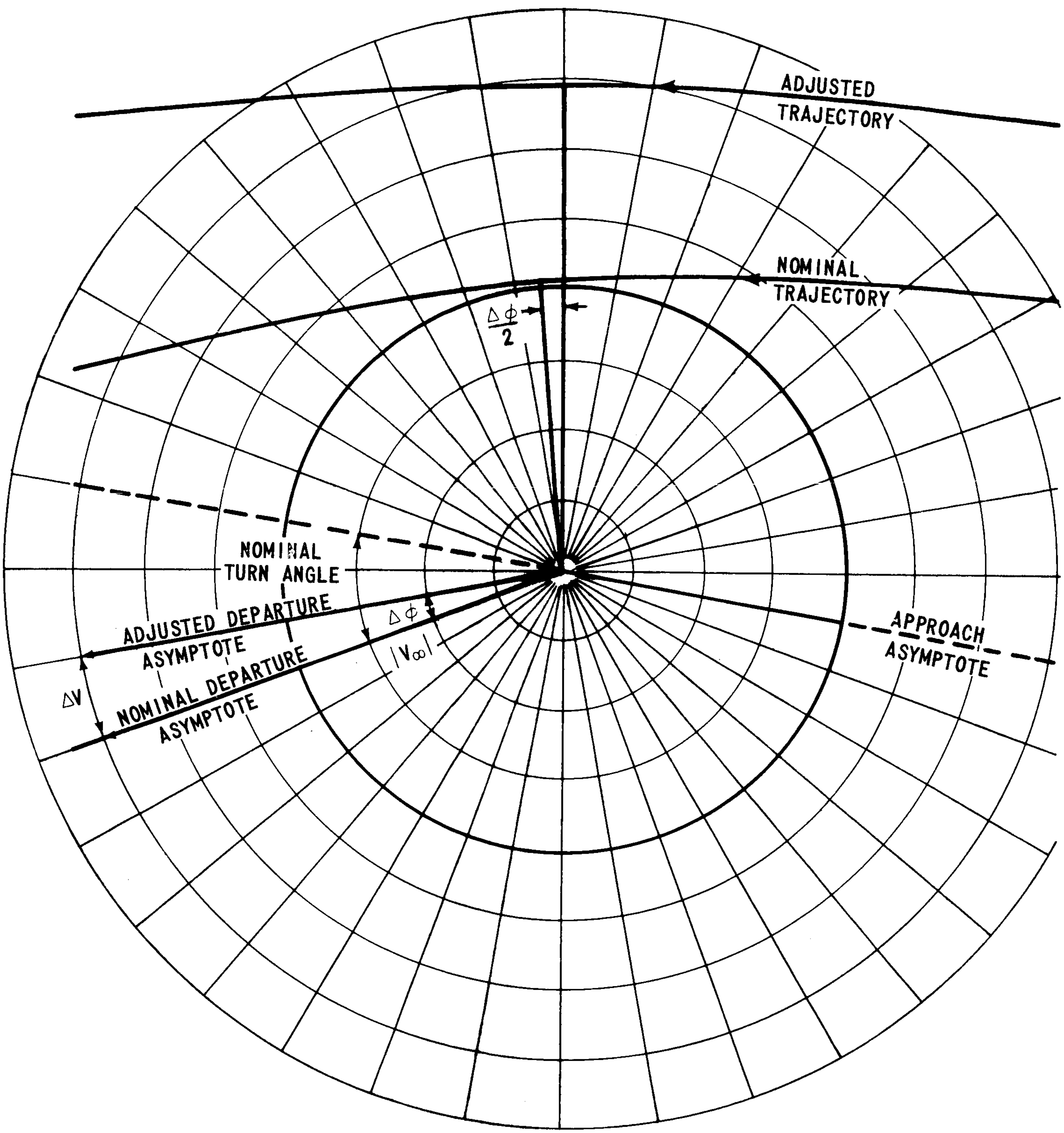

FIGURE 1 - ENCOUNTER GEOMETRY

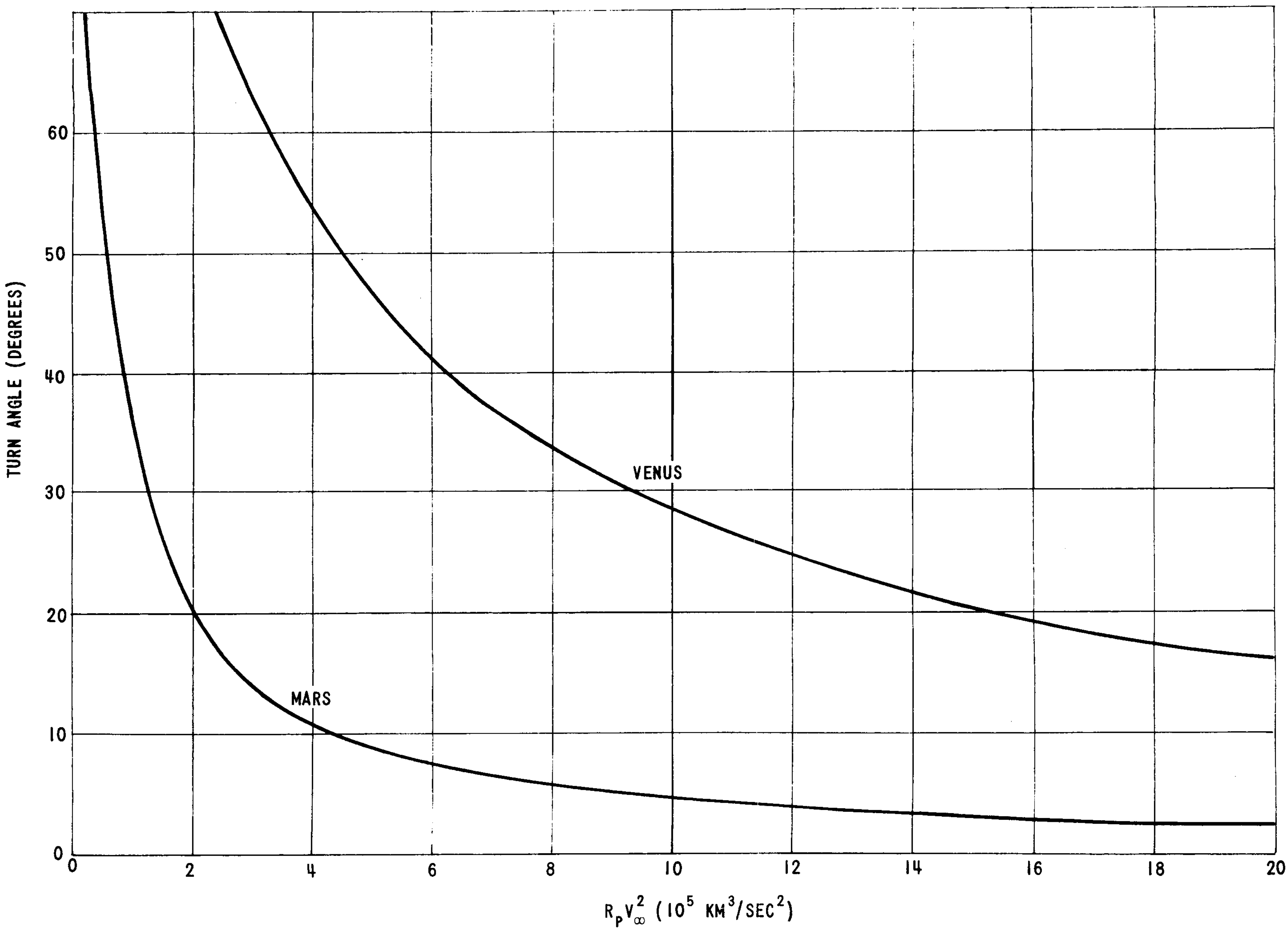

FIGURE 2 - TURN ANGLE (DEGREES) vs R_p V_∞^2 (10^5 KM^3/SEC^2)

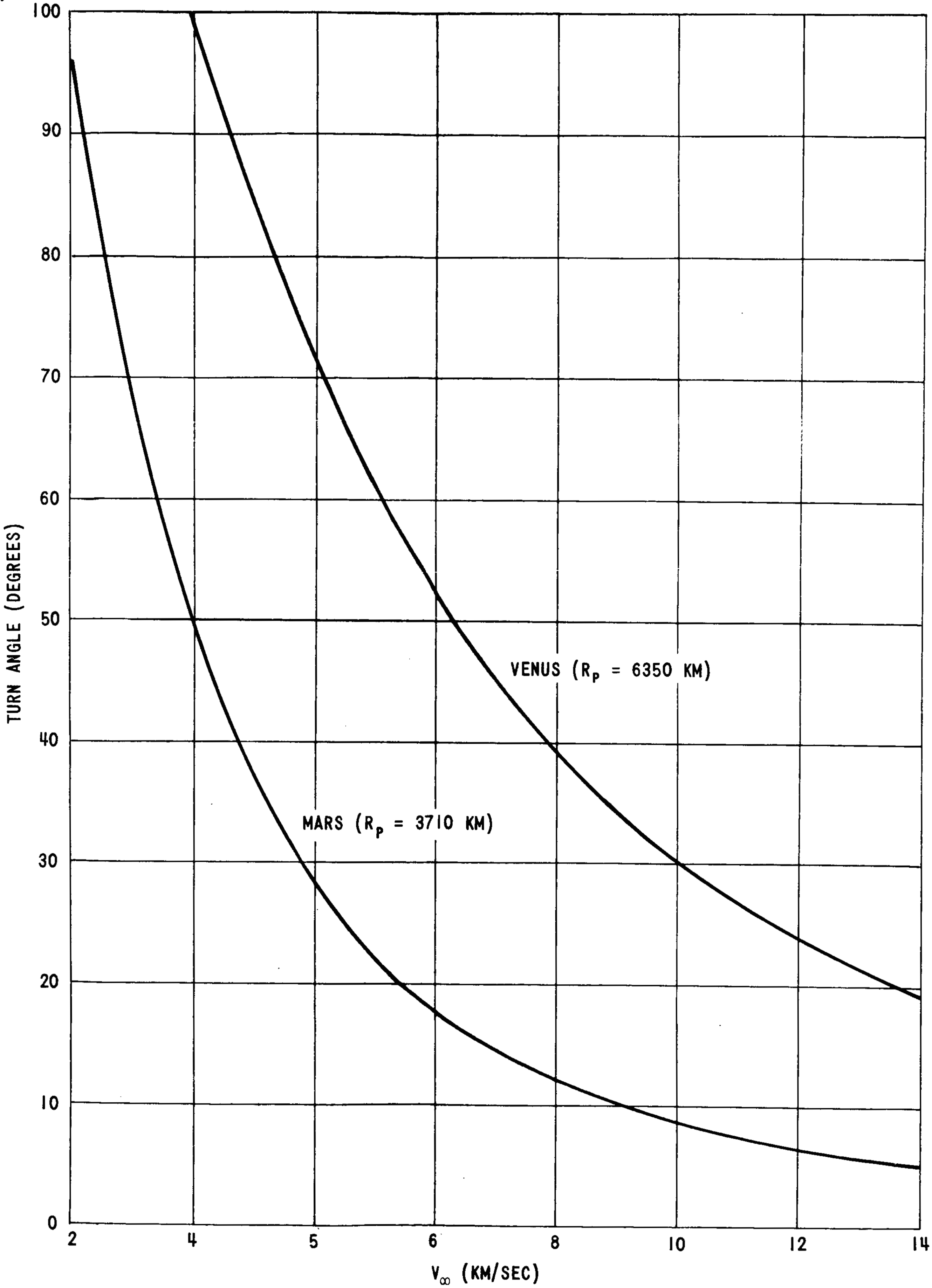

FIGURE 3 - TURN ANGLE (DEGREES) vs. V_∞ (KM/SEC)

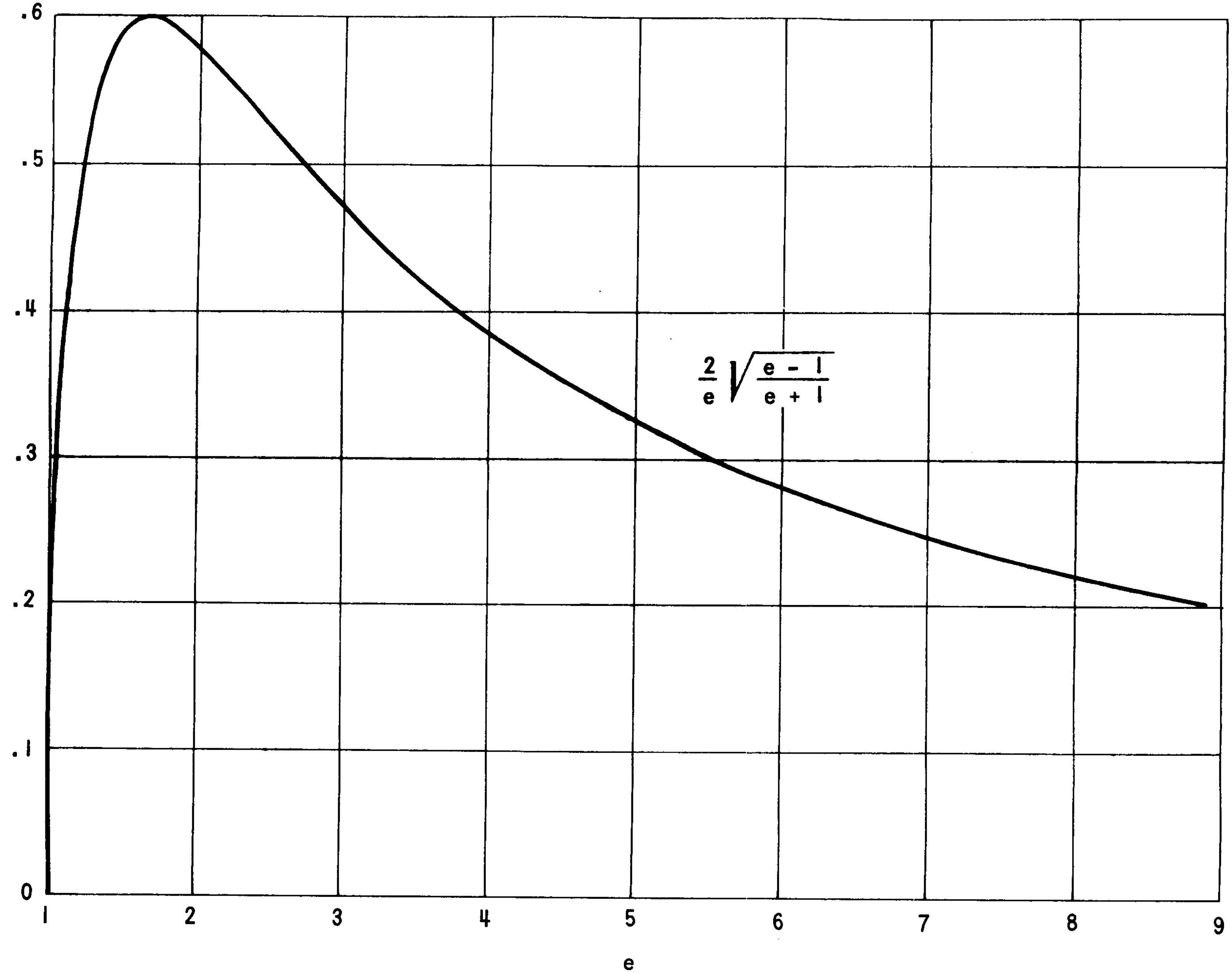

FIGURE 4

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